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QUALITY MAINTENANCE IN POLYETHYLENE-PACKAGED BROCCOLI



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PREFACE

U.S. Department of Agriculture marketing research is part of a continuing program to reduce marketing losses and to extend the marketing season of agricultural products. This study was undertaken to find improved methods for handling, packaging, and storing fresh broccoli.

The authors are grateful to Kari E. Olund, University of California, Davis, for technical assistance, to E. James Koch, Agricultural Research Service, for statistical analysis, and to Norman J. Smith, county agent, Cumberland, N.J., for assistance in obtaining freshly harvested broccoli.

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QUALITY MAINTENANCE IN POLYETHYLENE-PACKAGED BROCCOLI

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SUMMARY

This study was conducted to determine the effect of consumer packaging with perforated and sealed polyethylene film and holding at different temperatures on the keeping quality and subsequent shelf life of broccoli.

Nonwrapped broccoli held at 0° C was rated very good after 28 days with good green color but some turgor loss; at 10°, it was very good after 3 days and fair to poor after 7 days; and at 20°, it was good after 1 day and fair to poor after 2 days.

Broccoli in perforated 1.5-mil polyethylene packages held at 0° C was rated excellent after 28 days; at 10°, it was excellent after 3 days and good after 7 days; and at 20°, it was excellent after 1 day and good after 2 days. Anaerobic off-odor or off-flavor was not produced by nonwrapped broccoli or by broccoli in perforated packages.

Broccoli in sealed polyethylene packages maintained its green color and excellent flavor and resisted decay for 28 days at 0° C or 14 days at 10°, but at 20° it developed off-odor and off-flavor in 1 day. Off-odor and off-flavor in broccoli in sealed packages at 20° for 1 day were rated trace and dissipated subsequently on perforation of the packages; after 3 days, they were severe and persisted even after perforation or cooking; and after 7 days, broccoli remained green and turgid, but off-odor and off-flavor were offensive and persistent. Oxygen depletion and carbon dioxide accumulation in sealed packages accompanied anaerobic off-odor and off-flavor production.

Broccoli in perforated packages remained as turgid as that in sealed packages but yellowed as fast as nonwrapped broccoli, because perforated film restricted moisture loss but allowed considerable gas exchange.

In comparison with shelf life of freshly harvested broccoli, shelf life of broccoli at 20° C was longer following 0° but shorter following 10° holding. Improved keeping quality after 0° holding was indicated by slower rates of yellowing, ethylene production, and respiration. Slower metabolic rate was suggested as contributing to this slower deterioration.

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BACKGROUND

In modified atmosphere environments, where carbon dioxide (CO₂) concentration is increased and oxygen (O₂) is reduced, yellowing of broccoli is greatly retarded (9-11, 14, 18).^{2/} One method of obtaining a modified atmosphere that might be beneficial at certain temperatures is to package the commodity in sealed film. Being a relatively high CO₂ tolerant crop (13), broccoli could benefit greatly from film packaging. Packaging also reduces moisture loss and shrinkage, maintains fresh appearance, and increases consumers' acceptance (3, 5). However, many factors, such as permeability of the film, temperature, and time in the package, need to be considered when attempting to use film packages to develop desirable modified atmospheres through respiration of the product (4). In addition, prolonged exposure to high CO₂ and low O₂ and accompanying off-odor and off-flavor will adversely affect broccoli quality (6, 14).

A study (17) showed that broccoli was a good prepackaging prospect. Although off-odor accumulated in 2 days at 20° C in the nonperforated packages, it dissipated rapidly after opening. Packaging with Pliofilm, cellophane, and cellulose acetate has been tested as a supplement to refrigeration for maintaining good broccoli quality (7, 8). Overwrapping broccoli bunches with a shrink film at the shipping point has also been tried (2).

The present study was conducted to determine the effect of consumer packaging with perforated and sealed polyethylene film and holding at different temperatures on the keeping quality and subsequent shelf life of broccoli.

MATERIALS AND METHODS

'Waltham 29' broccoli grown in Bridgeton, N.J., was used in this study. The heads of central blooms were cut and placed in 1-1/9-bushel wire-bound wooden crates. During transportation from the field to the laboratory at the Beltsville Agricultural Research Center, Beltsville, Md., each crate surrounded by 10 kg of crushed ice was inside a polyethylene bag. Thermographs were inserted between broccoli heads in the crates to record temperatures. On arrival at the laboratory the crates were immediately placed in 0° C storage.

Broccoli heads were packaged at random at two different times. The first packaging was completed within 24 hours following harvest. The second was done after 7 days' storage at 0° C to determine the effect of delayed packaging on subsequent keeping quality and shelf life. The experiments were replicated twice or from two different harvests with samples from the same source and using the same handling procedures.

In each experiment, samples were placed in 1.5-mil polyethylene packages using four treatments and held at three temperatures for three or four periods. Each package contained two heads of broccoli and weighed about 0.5 kg. The four treatments were nonwrapped bunches, perforated film packages, sealed film

^{2/} Underlined numbers in parentheses refer to Literature Cited, p.13.

packages, and delayed perforated film packages. All polyethylene packages were closed by wire-twist ties. In the second treatment, the polyethylene packages were perforated initially with four 5-mm diameter holes. In the delayed perforated treatment, the packages were sealed at the start of the experiment, but when removed from the holding room and examined, they were perforated with ten 5-mm holes. More holes were punched in them than in the initially perforated packages to facilitate the gas exchange. After evaluation, samples from the last treatment were returned to the delayed perforated packages. The purpose of delayed perforation was to determine whether any anaerobic off-odor and off-flavor that might have developed in the sealed packages would dissipate after ventilation.

Two packages from each treatment were removed for evaluation after each holding period: At 0° C, for 7, 14, and 21 days; at 10°, for 3, 7, and 14 days; and at 20°, for 1, 2, 3, and 7 days. Relative humidity was maintained at 95 to 100 percent for 0°, 90 to 95 percent for 10°, and 50 percent for 20° holding. In the first experiment, the delayed perforated packages were saved following the evaluation and held for an additional 2 days at 20° to determine possible off-odor dissipation. In the second experiment, all packages from the four treatments were saved to evaluate off-odor and shelf life at 20°.

To determine keeping quality and shelf life, each bunch of broccoli was evaluated for its turgor, color, compactness, decay, off-odor, off-flavor, general appearance, and salability. To evaluate the odor and flavor of cooked broccoli, segments were boiled in water for 5 minutes. Descriptions of numerical ratings for each of these traits are given in table 1.

Table 1.--Description of numerical ratings for broccoli traits

Trait	Description of rating--					
	10	8	6	4	2	
Turgor-----	Turgid----	Less turgid.	Trace limp.	Limp----		
Color-----	Dark green.	Light green.	Slight yellow.			
Compactness----	Compact----	Trace loose.	Slight loose.	Moderate loose.	Severe loose.	Extremely loose.
Decay-----	None-----	1 spot ^{1/} -	2-4 spots.	5 or more spots.	General coverage.	Leaky mess.
Off-odor and off-flavor.	Normal----	Trace----	Slight--	Moderate-	Severe-----	Nauseating.
General appearance.	Excellent-	Good-----	Fair----	Poor----	Very poor.	Like garbage.
Salability-----	Attractive-	Accept- able.	Barely salable.	Not salable.	Barely salvageable.	Not salvageable.

^{1/} Each spot is a mold nest about 2 mm in diameter.

Each package was weighed initially and again at removal from the holding room to determine the effect of different packaging treatments on weight loss during holding. A 10-ml gas sample was taken with a syringe from each package atmosphere before opening to analyze O₂ and CO₂ concentrations. Respiration and ethylene (C₂H₄) production of broccoli were determined by enclosing 0.5-kg samples of broccoli in 4-liter plastic jars for 1 hour and measuring the accumulated CO₂ and C₂H₄. The O₂ and CO₂ were measured with a Fisher gas partitioner model 29, and C₂H₄ was determined with the standard gas chromatographic method (16).

RESULTS AND DISCUSSION

Since similar results were obtained with broccoli packaged immediately following harvest and after 7 days' storage at 0° C, the data were pooled and discussed as replications.

Film Packaging of Broccoli Held at 0°, 10°, or 20° C

At 0° C, nonwrapped broccoli remained green and free from decay for 21 days (table 2), but it was not in prime condition because of loss of moisture and turgidity. Since some broccoli had been previously stored at 0° for 7 days before packaging, this was equivalent to a total of 28 days at 0°. Broccoli in both perforated and sealed packages remained in freshly harvested condition after 21 days. The curds and leaves stayed turgid, green, and compact and no decay, off-odor, nor off-flavor was found.

At 10° C, nonwrapped broccoli was in excellent condition after 3 days, but it began to turn yellow in 7 days and became severely yellowed by the 14th day (table 2). Samples in perforated packages showed very little weight loss and stayed very turgid and compact throughout the 14-day period but yellowed at about the same rate as the nonwrapped samples. Apparently moisture was retained by the perforated film, but gas exchange was not markedly restricted. Thus, little or no CO₂ was accumulated to inhibit yellowing. Severe abscission of the florets was found at 14 days in the perforated packages but not in the nonwrapped samples. The high moisture content maintained in the perforated packages may have enhanced the formation of the abscission layer in the senescent florets. In the sealed packages, broccoli did not develop off-odor nor off-flavor and was still in good condition after 14 days at 10°. These samples had much better salability than those from the nonwrapped or the perforated treatments.

At 20° C, nonwrapped broccoli started to yellow on the second day and became severely yellowed on the third day (table 2). Only the broccoli in the perforated packages was salable on the second day. Samples in the sealed packages stayed green but developed offensive off-odor and off-flavor and became unsalable within 2 days.

Though very little weight was lost from perforated and sealed packages, the nonwrapped bunches lost 9.8, 15.0, and 58.7 percent in 7 days at 0°, 10°, and 20° C holding, respectively. Their ratings for general appearance were usually low because of wilted leaves and shriveled stems. Less decay was found in the nonwrapped samples, though, because of lack of moisture.

Table 2.--Condition of broccoli held for various periods in 3 package types at 3 temperatures and 3 relative humidities (RH)1/

Holding period and package type	Weight loss	Turgor	Color	Compactness	Decay	Off-odor when---		Off-flavor when--		General appearance	Salability
						Raw	Cooked	Raw	Cooked		
Held at 0° C and 95- to 100-percent RH											
<u>7 days</u>											
Nonwrapped-----	9.8 c	8.8 a	10.0 a	9.4 b	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.9 a	9.9 a
Perforated-----	.1 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Sealed-----	.0 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
<u>14 days</u>											
Nonwrapped-----	16.2 b	6.1 b	10.0 a	8.7 c	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.4 b	9.4 b
Perforated-----	.3 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Sealed-----	.2 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
<u>21 days</u>											
Nonwrapped-----	21.3 a	5.9 b	10.0 a	8.1 c	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.3 b	9.0 c
Perforated-----	.4 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Sealed-----	.1 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
<u>3 days</u>											
Held at 10° C and 90- to 95-percent RH											
Nonwrapped-----	10.6 c	8.6 b		8.9 b	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.2 a	9.2 ab
Perforated-----	.3 d	10.0 a		.0 a	9.9 a	10.0 a	10.0 a	10.0 a	10.0 a	9.9 a	10.0 a
Sealed-----	.1 d	10.0 a		.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
<u>7 days</u>											
Nonwrapped-----	15.0 b	3.8 c		.2 c	9.5 ab	10.0 a	10.0 a	10.0 a	10.0 a	5.1 d	4.9 d
Perforated-----	.3 d	9.8 a		.8 a	7.2 c	10.0 a	10.0 a	10.0 a	10.0 a	7.9 bc	7.4 c
Sealed-----	.2 d	10.0 a		.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a

Table 2.--Condition of broccoli held for various periods in 3 package types at 3 temperatures and 3 relative humidities (RH) ^{1/} --Continued

Holding period and package type	Weight loss	Turgor	Color	Compactness	Decay	Off-odor when--		Off-flavor when--		General appearance	Salability
						Raw	Cooked	Raw	Cooked		
Held at 10° C and 90- to 95-percent RH--Continued											
<u>14 days</u>											
Nonwrapped-----	25.2 a	2.4 d	2.4 c	6.6 d	8.4 abc	10.0 a	10.0 a	10.0 a	10.0 a	3.2 e	2.4 e
Perforated-----	.7 d	10.0 a	2.8 c	10.0 a	3.9 d	10.0 a	10.0 a	10.0 a	10.0 a	3.2 e	2.6 e
Sealed-----	.4 d	10.0 a	9.5 a	10.0 a	7.4 bc	10.0 a	10.0 a	10.0 a	10.0 a	7.6 c	8.1 bc
<u>1 day</u>											
Held at 20° C and 50-percent RH											
Nonwrapped-----	15.2 d	5.4 b	9.5 a	8.2 b	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	8.4 b	8.4 ab
Perforated-----	.8 f	10.0 a	9.7 a	10.0 a	9.5 ab	10.0 a	10.0 a	10.0 a	10.0 a	9.6 ab	9.4 ab
Sealed-----	.1 f	10.0 a	10.0 a	10.0 a	10.0 a	7.6 b	9.4 a	8.7 a	9.6 a	10.0 a	9.6 a
<u>2 days</u>											
Nonwrapped-----	25.5 c	4.0 b	5.4 b	6.4 c	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	5.2 d	4.6 c
Perforated-----	1.3 f	10.0 a	5.5 b	10.0 a	8.1 b	10.0 a	10.0 a	10.0 a	10.0 a	6.9 c	7.1 b
Sealed-----	.3 f	10.0 a	9.9 a	10.0 a	9.5 ab	4.8 c	7.9 b	6.5 b	6.9 b	9.8 a	5.4 c
<u>3 days</u>											
Nonwrapped-----	32.9 b	2.6 b	2.9 c	4.9 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	3.1 e	1.9 de
Perforated-----	1.6 ef	9.8 a	3.0 c	9.4 a	4.8 c	10.0 a	10.0 a	10.0 a	10.0 a	3.4 e	2.8 d
Sealed-----	.6 f	10.0 a	10.0 a	9.9 a	8.9 ab	2.5 d	6.6 c	5.6 b	5.5 c	9.3 ab	5.2 c
<u>7 days</u>											
Nonwrapped-----	58.7 a	3.0 b	.9 d	3.6 e	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	2.0 fg	1.4 de
Perforated-----	4.7 e	9.9 a	1.2 d	9.5 a	1.2 d	10.0 a	10.0 a	10.0 a	10.0 a	.9 g	.6 e
Sealed-----	1.2 f	10.0 a	9.7 a	9.9 a	2.0 d	2.6 d	5.8 c	5.0 b	4.9 c	2.9 ef	1.9 de

^{1/} Each value is based on 8 bunches of 2 heads each in 4 replicate packagings. For description of ratings, see table 1. Mean separation in columns within temperature was done by Duncan's multiple range test at 5-percent level. Comparable values followed by no letters in common are significantly different.

A comparison between broccoli held at different temperatures in various package types for 7 days revealed that, except for weight loss, greater differences were found between temperatures than between package types within a given temperature (table 3). Significant differences between package types occurred at 10° and 20° C, whereas no difference was observed at 0° within most parameters evaluated. Except for weight loss of the nonwrapped samples, all other traits examined were rated excellent at 0° regardless of the type of package. The data indicated that this low temperature was the most effective way to maintain good quality in broccoli during holding, and packaging could only be considered as a supplement to refrigeration. Packaging in polyethylene greatly reduced weight loss at the three temperatures tested. In addition, at 10°, packaging benefited broccoli in several of the other quality traits tested. However, at 20°, low ratings were given for general appearance and salability of broccoli in all three package types.

Shelf Life as Affected by Packaging and Previous Holding Conditions

Shelf life of broccoli is often terminated by yellowing. The yellow detracts from appearance, reduces consumers' acceptance, and overrides any other factors in determining the salability of the commodity. Freshly harvested broccoli yellows much faster than broccoli held previously at 0° C (table 4). Samples freshly picked from the field became moderately yellow in 2 days at 20° and became severely yellowed after the third day. In contrast to expectation, samples that had been held at 0° for 28 days changed color at a much slower rate and maintained their green color in acceptable condition on the third day after transfer to 20°. The reason for this is not clear. It is suspected that the metabolic rates of samples previously held at 0° might have been slower than rates for freshly harvested samples. This is supported by the slower rates of respiration and ethylene production (table 4). Whether this was a result of the suppression of overall metabolism at cold temperature or because of a slowing down of chlorophyll breakdown in the aged samples or because of some other factors was not determined.

The keeping quality of the samples in perforated packages after 0° C holding was generally better than that in sealed packages (table 5). Retention of turgor, compactness, and appearance was higher in perforated packages, resulting in higher quality and salability. All samples had acceptable appearance at 20° following removal from 7 days of holding. After 14 or 21 days, the nonwrapped samples were in unacceptable condition on the second day at 20° primarily because of shriveled samples. Samples in perforated or sealed packages were still in acceptable condition. With longer holding at 0°, yellowing after transfer to 20° was more pronounced.

Holding temperature of 10° C was not sufficient to retard deterioration of broccoli. Consequently, deterioration was accelerated after holding at 10° (table 5). Besides yellowing, decay was noted, especially in the perforated packages. The high humidity and O₂ and low CO₂ in the perforated packages are an environment for mold growth. However, decay was not observed in sealed packages possibly because it was inhibited by the low humidity.

Table 3.--Comparison of broccoli held at different temperatures in various package types for 7 days^{1/}

Temperature (°C)	Package type	Weight loss	Turgor	Color	Compactness	Decay	Off-odor when---		Off-flavor when---		General appearance	Salability
							Raw	Cooked	Raw	Cooked		
Percent												
0-----	Nonwrapped-	9.8 c	8.8 a	10.0 a	9.4 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.9 a	9.9 a
	Perforated-	.1 e	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
	Sealed-----	0 e	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
10-----	Nonwrapped-	15.0 b	3.8 b	7.1 b	7.2 b	9.5 a	10.0 a	10.0 a	10.0 a	10.0 a	5.1 c	4.9 c
	Perforated-	.3 e	9.8 a	7.8 b	9.8 a	7.2 b	10.0 a	10.0 a	10.0 a	10.0 a	7.9 b	7.4 b
	Sealed-----	.2 e	10.0 a	10.0 a	10.0a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
20-----	Nonwrapped-	58.7 a	3.0 b	.9 c	3.6 c	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	2.0 de	1.4 de
	Perforated-	4.7 d	9.9 a	1.2 c	9.5 a	1.2 c	10.0 a	10.0 a	10.0 a	10.0 a	.9 e	.6 e
	Sealed-----	1.3 e	10.0 a	9.7 a	9.9 a	2.0 c	2.6 b	5.8 b	5.0 b	4.9 b	2.9 d	1.9 d

^{1/} Each value is based on 8 bunches of 2 heads each in 4 replicate packagings. For description of ratings, see table 1. Mean separation in columns was done by Duncan's multiple range test at 5-percent level. Comparable values followed by no letters in common are significantly different.

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Table 4.--Color change, respiration rate, and ethylene production at 20° C in broccoli bunches freshly harvested or held 28 days at 0° and 95- to 100-percent relative humidity^{1/}

Broccoli condition	Results after indicated days at 20° C in---								
	Color change ^{2/}		Respiration (CO ₂ mg/kg/hr)		Ethylene production (μl/kg/hr)				
	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{1}{2}$	$\frac{3}{2}$			
Freshly harvested---	9.0 ab	5.6 c	2.8 d	376.7 a	349.4 a	318.9 b	9.2 a	5.4 b	3.7 c
After holding-----	10.0 a	9.7 a	8.2 b	181.8 c	197.9 c	176.4 c	2.8 d	3.1 d	1.6 e

^{1/} Each value is based on 2 containers holding 0.5 kg of broccoli. Mean separation in each category was done by Duncan's multiple range test at 5-percent level. Comparable values followed by no letters in common are significantly different.

^{2/} For description of ratings, see table 1.

Table 5.--Condition of packaged broccoli after 1 and 2 days' shelf life at 20° C and 50-percent relative humidity when held for various periods at 2 temperatures and 2 relative humidities (RH) 1/

Days shelf life held at 20° C	Days of	Package type	Turgor	Color	Compactness	Decay	Off-odor when--		Off-flavor when--		General appearance	Salability
							Raw	Cooked	Raw	Cooked		
Held at 0° C and 95- to 100-percent RH												
7-----1-----		Nonwrapped----	4.8 b	9.8 ab	7.0 bcd	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	8.5 abc	8.4 abc
		Perforated----	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
		Sealed-----	10.0 a	10.0 a	10.0 a	10.0 a	9.0 a	10.0 a	10.0 a	10.0 a	9.9 a	9.8 ab
2-----		Nonwrapped----	3.2 bc	8.8 e	6.0 cd	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	6.8 de	6.3 de
		Perforated----	10.0 a	9.1 cde	10.0 a	8.0 ab	10.0 a	10.0 a	10.0 a	10.0 a	9.1 ab	8.8 abc
		Sealed-----	10.0 a	9.9 a	10.0 a	10.0 a	9.0 a	10.0 a	10.0 a	10.0 a	9.9 a	9.9 ab
14-----1-----		Nonwrapped----	3.5 bc	9.9 a	7.8 bc	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	7.8 bcd	7.0 cd
		Perforated----	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
		Sealed-----	10.0 a	10.0 a	10.0 a	10.0 a	9.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.5 ab
2-----		Nonwrapped----	2.0 c	9.0 de	6.5 cd	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	6.0 e	5.2 e
		Perforated----	10.0 a	9.4 bcd	10.0 a	7.5 b	10.0 a	10.0 a	10.0 a	10.0 a	8.8 ab	8.1 bc
		Sealed-----	10.0 a	10.0 a	10.0 a	10.0 a	9.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.5 ab
21-----1-----		Nonwrapped----	3.0 bc	10.0 a	6.8 cd	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	7.0 cde	6.2 de
		Perforated----	10.0 a	10.0 a	10.0 a	8.5 ab	10.0 a	10.0 a	10.0 a	10.0 a	9.8 a	8.8 abc
		Sealed-----	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
2-----		Nonwrapped----	2	9.6 abc	5.2 d	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	6.0 e	5.2 e
		Perforated----	8	9.6 abc	8.8 ab	7.8 ab	10.0 a	10.0 a	10.0 a	10.0 a	8.0 bcd	7.5 cd
		Sealed-----	9	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Held at 10° C and 90- to 95-percent RH												
3-----1-----		Nonwrapped----	4	7.2 b	7.2 b	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	7.6 b	8.0 ab
		Perforated----	10	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	9.0 ab	9.0 a
		Sealed-----	10	10.0 a	10.0 a	10.0 a	8.6 b	10.0 a	10.0 a	10.0 a	10.0 a	8.8 ab
2-----		Nonwrapped----	3	5.6 cd	5.6 cd	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	4.8 de	4.3 c
		Perforated----	10	10.0 a	7.6 abc	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	7.5 b	7.0 ab
		Sealed-----	10	10.0 a	10.0 a	10.0 a	8.0 b	10.0 a	10.0 a	10.0 a	10.0 a	8.8 ab

Table 5.--Condition of packaged broccoli after 1 and 2 days' shelf life at 20° C and 50-percent relative humidity when held for various periods at 2 temperatures and 2 relative humidities (RH)1/--Continued

Days shelf life held at 20° C	Days of	Package type	Turgor	Color	Compactness	Decay	Off-odor when--		Off-flavor when--		General appearance	Salability
							Raw	Cooked	Raw	Cooked		
Held at 10° C and 90- to 95-percent RH--Continued												
7-----1-----		Nonwrapped--	2.5 d	5.1 bcd	6.5 bc	9.5 ab	10.0 a	10.0 a	10.0 a	10.0 a	4.5 def	3.0 cd
		Perforated--	10.0 a	5.5 b	10.0 a	6.5 bcd	10.0 a	10.0 a	10.0 a	10.0 a	7.0 bc	6.8 b
		Sealed-----	10.0 a	9.8 a	10.0 a	9.0 abc	9.0 ab	10.0 a	10.0 a	10.0 a	9.2 ab	9.0 a
2-----		Nonwrapped--	1.5 e	3.0 de	5.0 de	9.0 abc	10.0 a	10.0 a	10.0 a	10.0 a	2.5 efg	2.0 d
		Perforated--	10.0 a	3.2 cde	10.0 a	2.5 c	10.0 a	10.0 a	10.0 a	10.0 a	3.5 defg	2.6 cd
		Sealed-----	10.0 a	9.2 a	10.0 a	6.0 cd	9.0 ab	10.0 a	10.0 a	10.0 a	8.1 ab	7.9 ab
14-----1-----		Nonwrapped--	1.0 f	1.8 e	4.5 de	8.5 abc	10.0 a	10.0 a	10.0 a	10.0 a	2.2 fg	2.0 d
		Perforated--	10.0 a	2.2 e	10.0 a	2.5 e	10.0 a	10.0 a	10.0 a	10.0 a	3.0 defg	2.3 cd
		Sealed-----	10.0 a	8.9 a	10.0 a	6.5 bcd	9.0 ab	10.0 a	10.0 a	10.0 a	7.2 b	7.0 ab
2-----		Nonwrapped--	.7 f	1.2 e	4.2 e	8.0 abc	10.0 a	10.0 a	10.0 a	10.0 a	2.0 g	2.0 d
		Perforated--	10.0 a	2.0 e	10.0 a	2.0 e	10.0 a	10.0 a	10.0 a	10.0 a	2.0 g	2.0 d
		Sealed-----	10.0 a	7.9 a	10.0 a	3.5 de	9.0 ab	10.0 a	10.0 a	10.0 a	5.0 cd	4.0 cd

1/ All packages were opened for evaluation daily. For description of ratings, see table 1. Mean separation in columns within temperature was done by Duncan's multiple range test at 5-percent level. Comparable values followed by no letters in common are significantly different.

florets and leaves of the nonwrapped samples rapidly became dry and sometimes brittle after being transferred from 0° or 10° to 20°. Their off-odor and off-flavor resembled dried hay or straw. Therefore retention of flavor was another benefit obtained from packaging.

After 3 days' holding at 10° C, the nonwrapped bunches had similar rates of yellowing to those in perforated packages but were not marketable on the second day because of loss of turgidity and compactness. The samples in the perforated and sealed packages had 2 days of shelf life at 20°. After 7 days' holding at 10°, nonwrapped broccoli had no market value because of yellowing and shriveling. However, the samples in perforated and sealed packages had 1 and 2 days of shelf life at 20°, respectively. After 14 days' holding at 10°, only samples from sealed packages retained salable quality after 1 day at 20°. None of the treatments were acceptable after 2 days at 20° because of yellowing and wilting of the nonwrapped samples and moderate to severe decay of the samples in perforated and sealed packages (table 5).

Anaerobic Off-Odor and Off-Flavor Associated With In-Package Atmosphere

No anaerobic off-odor nor off-flavor was found in any sample of broccoli held at 0° C for up to 21 days or at 10° for 14 days (table 2). At 20°, trace off-odor and off-flavor were detected in sealed packages after 1 day; off-odor and off-flavor were slight after 2 days and severe after 3 days. The off-odor and off-flavor accumulated after 1 or 2 days' enclosure dissipated after the polyethylene packages were perforated (table 6). The off-odor and off-flavor persisted, however, after 3 days' enclosure and did not dissipate even after perforation. There were some differences between raw and cooked odor or flavor. The off-odor and off-flavor tended to be less intensive and often ephemeral after cooking.

Dissipation of off-odor has also been reported by others (6). Off-odor was found to develop in broccoli after being in 10 percent CO₂ for 17 days at 2.5° C, but it disappeared upon returning broccoli to air. The nauseating off-odor and off-flavor induced by low O₂ atmosphere also tended to disappear upon aeration (14).

Measurement of the atmosphere in the perforated packages showed that CO₂ concentration never exceeded 1.6 percent and O₂ levels were always above 16.7 percent (table 7). Off-odor was not noted in any of these packages. Measurement of the atmosphere in sealed packages revealed that off-odor was associated with high CO₂ and low O₂. At 0° or 10° C where respiration was suppressed, less accumulation of CO₂ or depletion of O₂ was detected and off-odor did not develop. In the 20° holding room, the CO₂ level rose to an average of 7.1 percent, O₂ decreased to 5.2 percent, and trace off-odor was detected in 1 day in the sealed packages. On the second day, O₂ dropped to 2.9 percent, CO₂ increased to 8.5 percent, and moderate off-odor was detected. By the third day, a strong fermentation odor could be detected, indicating some anaerobic respiration had taken place under the atmosphere of 1.8 percent O₂ and 12.6 percent CO₂ (table 7).

Table 6.--Off-odor and off-flavor of raw and cooked broccoli held in polyethylene packages at 20° C before and after perforation^{1/}

Days held	Ratings following perforation after indicated days for--									
	Off-odor when--					Off-flavor when--				
	Raw		Cooked			Raw		Cooked		
	0	1	2	0	1	2	0	1	2	0
1-----	7.2 b	10.0 a	10.0 a	8.6 abc	10.0 a	10.0 a	8.4 ab	10.0 a	10.0 a	8.8 a
2-----	5.2 c	7.9 b	10.0 a	7.3 bc	9.0 ab	10.0 a	6.8 bc	8.2 ab	10.0 a	8.3 ab
3-----	3.6 d	3.8 cd	4.2 cd	6.6 c	7.4 bc	9.2 ab	5.6 c	5.9 c	6.2 c	5.9 c
										6.4 bc
										8.2 ab

^{1/} Each value is based on 8 bunches of 2 heads each in 4 replicate packagings. For description of ratings, see table 1. Mean separation in each category was done by Duncan's multiple range test at 5-percent level. Comparable values followed by no letters in common are significantly different.

Table 7.--Anaerobic off-odor and CO₂ and O₂ content of atmospheres in perforated and sealed packages of broccoli held for various periods at 3 temperatures^{1/}

Treatment	Results after indicated days when held at---									
	0° C			10° C			20° C			
	7	14	21	3	7	14	1	2	3	7
Perforated:										
Off-odor---rating ^{2/} ---	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
CO ₂ -----percent----	.2 mn	.1 n	.2 mn	.6 lm	.8 kl	.5 lmn	.7 l	1.2 jk	1.6 j	.5 lmn
O ₂ -----percent----	20.8 ab	21.2 a	20.4 b	18.7 d	17.9 ef	20.2 bc	18.8 d	17.4 fg	16.8 g	19.6 c
Sealed:										
Off-odor---rating ^{2/} ---	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	7.6 b	4.8 c	2.5 d	2.6 d
CO ₂ -----percent----	2.4 i	3.2 h	3.8 g	4.6 f	5.4 e	7.2 d	7.1 d	8.5 c	12.6 b	13.5 a
O ₂ -----percent----	18.2 de	16.7 g	15.6 h	14.8 i	13.2 j	11.9 k	5.2 e	2.9 m	1.8 n	1.6 n

^{1/} Values are means of 8 packages. Mean separation of 20 values within each parameter was done by Duncan's multiple range test at 5-percent level. Comparable values followed by no letters in common are significantly different.

^{2/} For description of ratings, see table 1.

Polyethylene film is more permeable to CO₂ than to O₂ (1). Free O₂ was rapidly used up in the sealed packages and followed by the accumulation of CO₂. Respiration of broccoli became anaerobic and suboxidation flavor developed in the packages. Products of anaerobic metabolism, such as ethyl acetate and acetaldehyde, have been identified in volatiles of broccoli (12). The quantity of this nonethylenic fraction production increased rapidly as O₂ concentration dropped below 2.5 percent.

CONCLUSIONS

As has been shown in these experiments, retardation of yellowing, retention of flavor, and reduction of weight loss are some of the benefits obtained from film packaging of broccoli. As a supplement to good refrigeration, perforated or sealed polyethylene packages will retain turgidity and freshness and improve keeping quality. Results of this study indicate that broccoli can be held in either perforated or sealed 1.5-mil polyethylene packages at 0° C for 28 days and still maintain excellent appearance after at least 2 days of shelf life at 20°. This holding time is double what has been reported previously (15). However, sealed packages should be adequately perforated or opened upon transfer from 0° to higher temperatures to allow gas exchange during retailing and thus avoid development of off-odor and off-flavor.

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